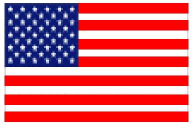
The Fermilab/NICADD photo-injector laboratory

➢FNPL is a collaborative effort amongst several institutes and universities to operate a high-brightness electron photo-injector dedicated to fundamental and advanced accelerator R&D

➢Main support comes from FNAL & North Illinois Center of Accelerator & Detector Development (NICADD)

➢Collaborators includes:



U. of Chicago, U. of Rochester, UCLA,
U. of Indiana, U. of Michigan, LBNL, NIU,
U. of Giorgia, Jlab, Cornell University

DESY, INFN-Milano, IPN-Orsay
CEA-Saclay

➢ The present talk highlights some of the past month activities and present our short term plans.

The FNPL experiment

- **Since mid 90's:** FNAL operates a high brightness photo-injector (A0 now FNPL)

- Copy of FNPL was installed at TTF-1 (DESY) and supported SASE-FEL operation (100 nm)

Main beam parameters:

E= 16 MeV

Q= 0 to 15 nC,

ε_T =3.7 mm-mrad (1 nC)

$\delta p/p$=0.25 % (1 nC)

I_{peak} = 75-330 A (BC off)

I_{peak} = 200-1700 A (BC on)

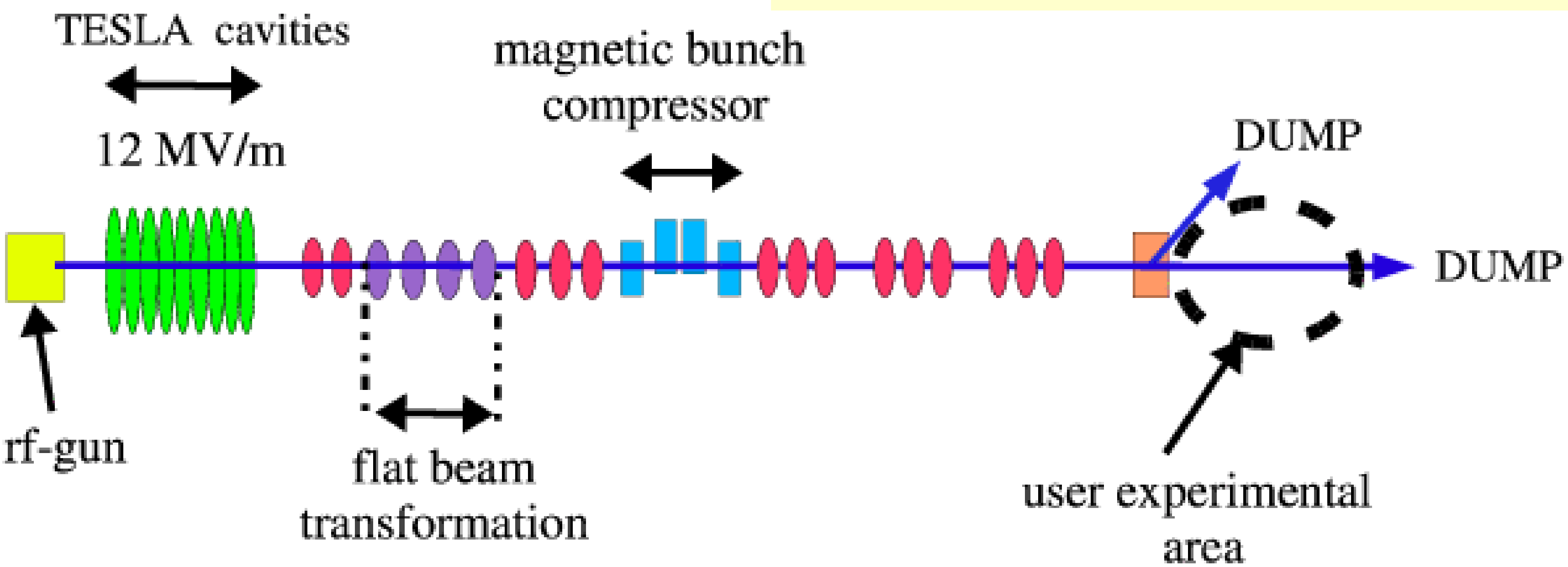
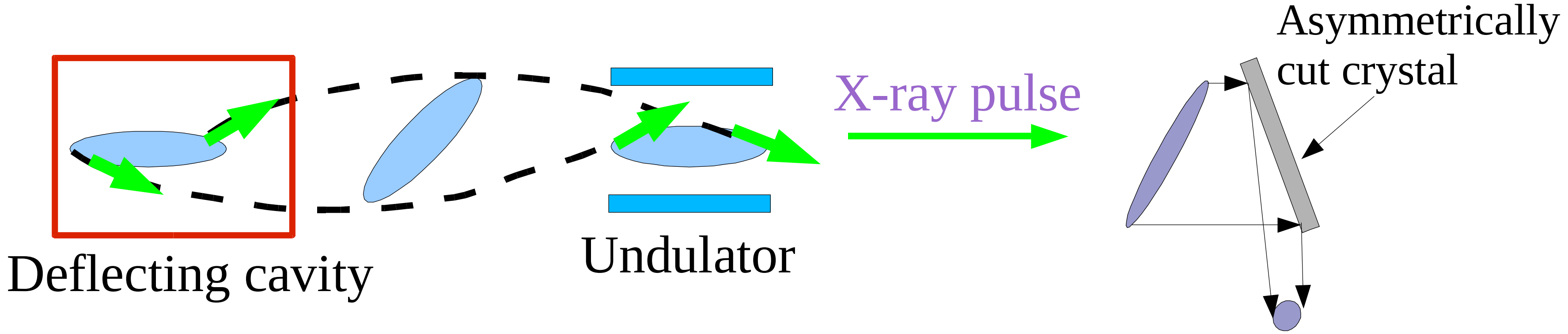


Photo-injector production of flat beams: potential applications

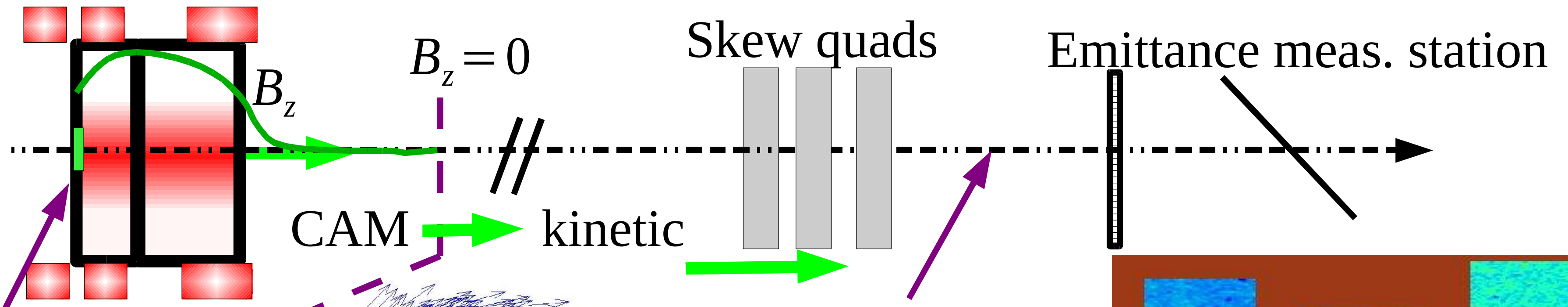
- Flat beams for linear colliders are generally obtained in damping rings. For electrons, flat beams may be generated directly from a photo-injector as suggested by *Brinkmann et al. U*sing Derbenev transform. Such an alternative may result in relaxed requirements on the e- damping ring

- Flat beams in conjunction with deflecting cavity are foreseen to be used in light sources for generating ultrashort (femtosecond) X-ray pulse (e.g. LUX proposal at LBNL)

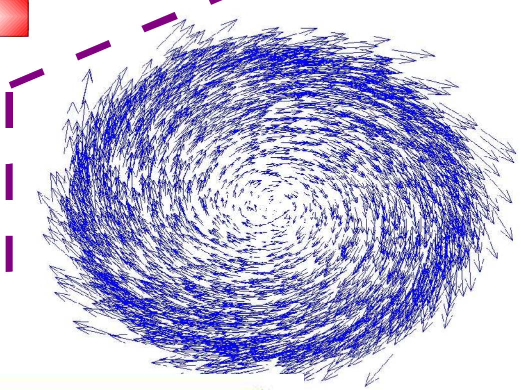


- Flat beams are natural candidates for Smith-Purcell based radiation source

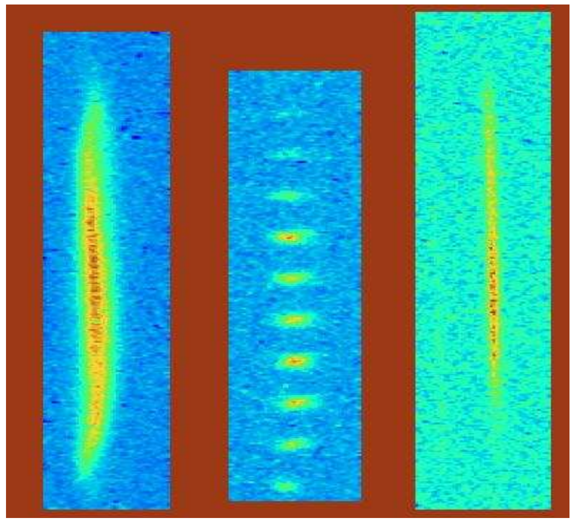
Photo-injector production of flat beams: demonstration



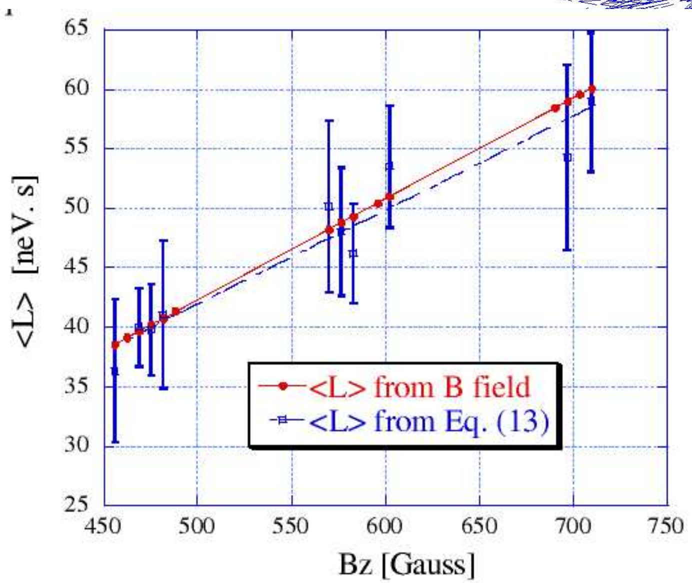
$$\boldsymbol{L} = \frac{er^2}{2} B_z$$



$$\frac{\varepsilon_x}{\varepsilon_y} - 1 \propto B_z^2 \frac{\sigma_r^2}{\sigma_{r'}^2}$$



SPOT YMS XMS

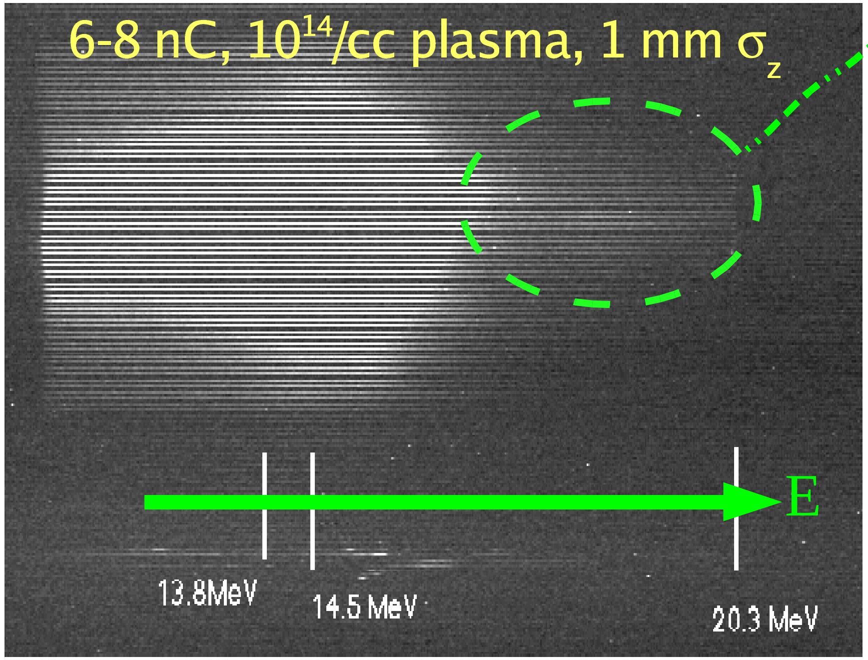


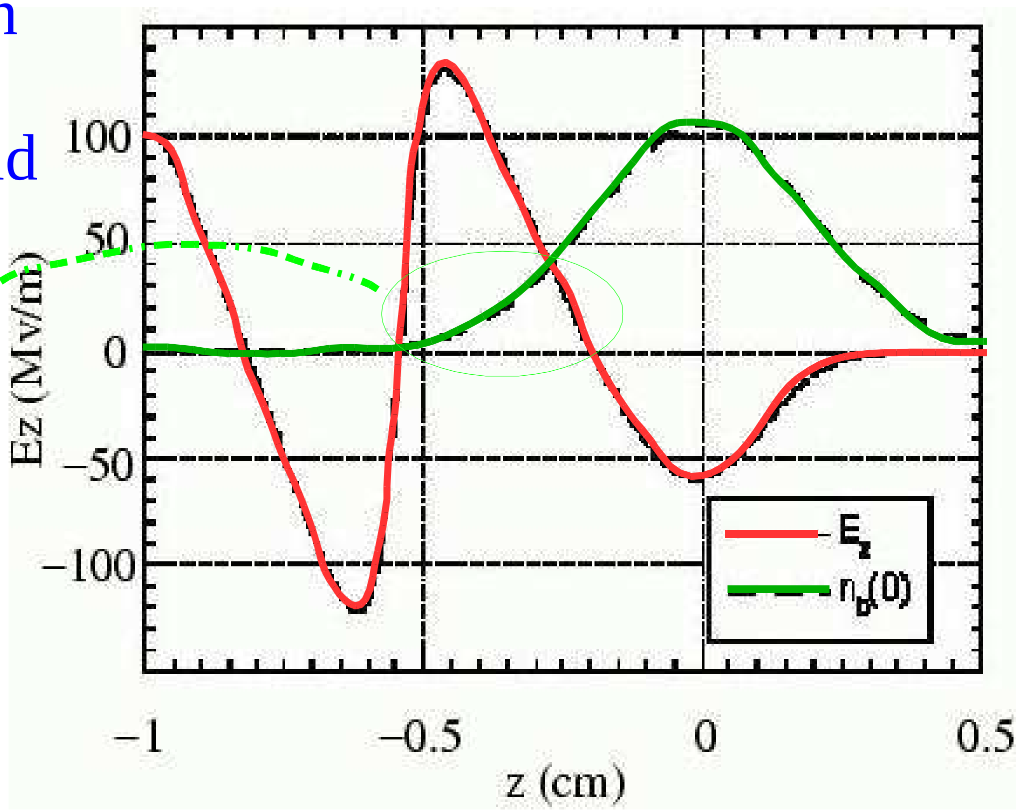
- Proof-of-principle experiment done
- Measured emittance: $\frac{\varepsilon_y}{\varepsilon_x} = 45/0.9 \simeq 50$
- Now working toward emittance ratio > 100

Ph. Piot, AAC meeting Nov. 19, 2003

Plasma-wakefield acceleration of electrons

- High current e- beam injected in a plasma induces density modulation
- Energy in the bunch is modified according to the induced wake-field

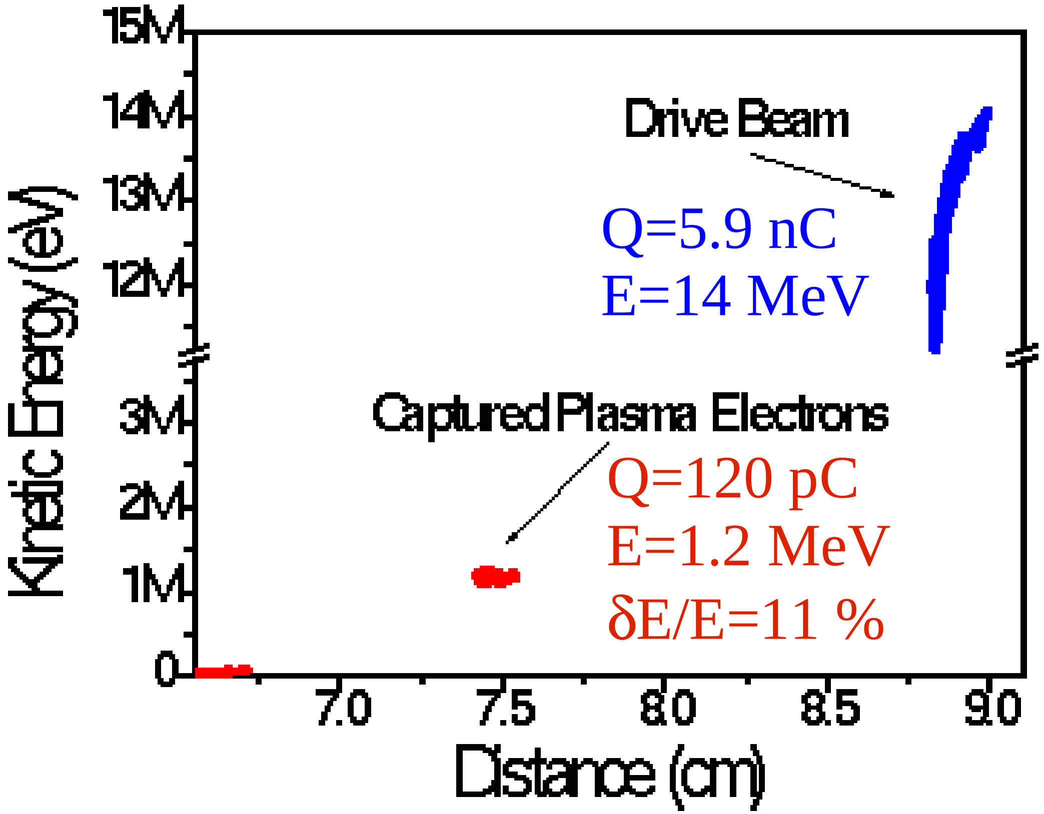


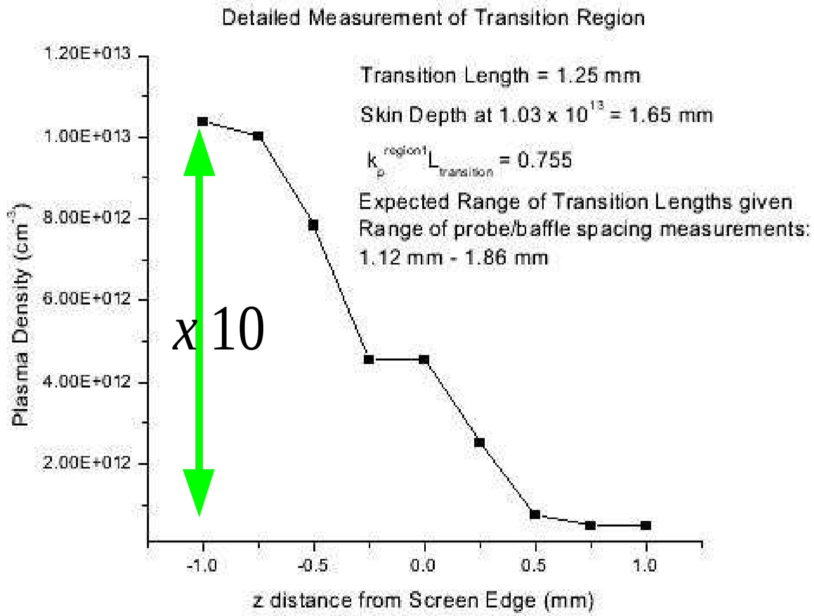


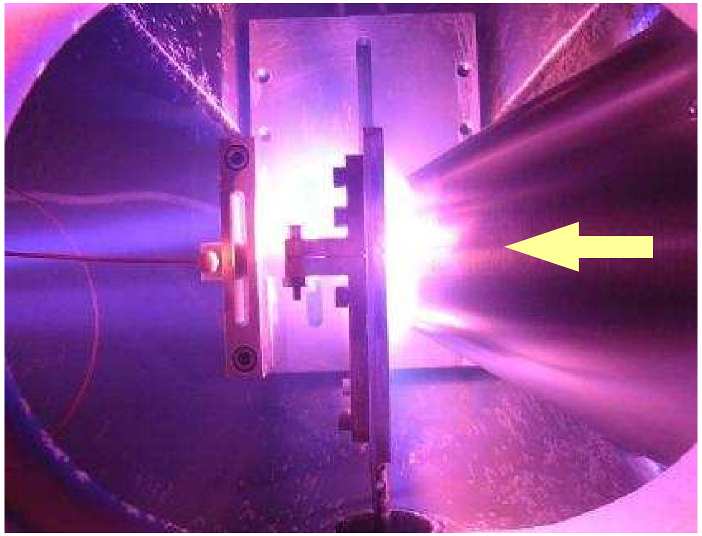
- Demonstrated energy gradient of ~ 100 MeV/m
- Present experiment aims in sampling the plasma wake using a witness bunch following the drive beam

Plasma-wakefield generation of electrons

- Self-trapping mechanism based on rapid change in the wake-field wavelength at a steep transition in the plasma density
- Plasma electrons are dephased into an accelerating field of the plasma wake







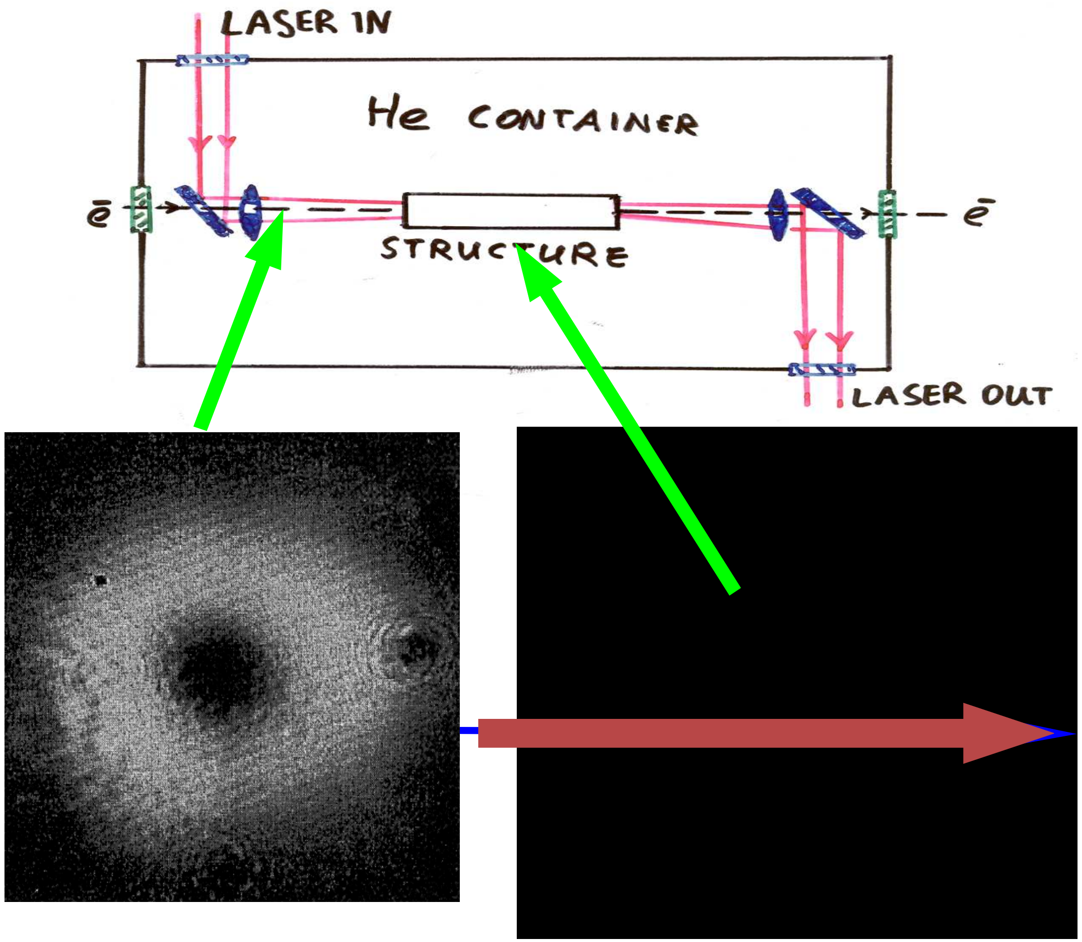
Laser-based acceleration of electrons (R&D on laser)

UNIVERSITY OF ROCHESTER

- Laser beam is used to provide longitudinal accelerating E-field
- **The promise**: 0.54 GV/m for 34 TW laser

- laser and e- beams are "coupled" in the "open iris structure" (radius>>wavelength)

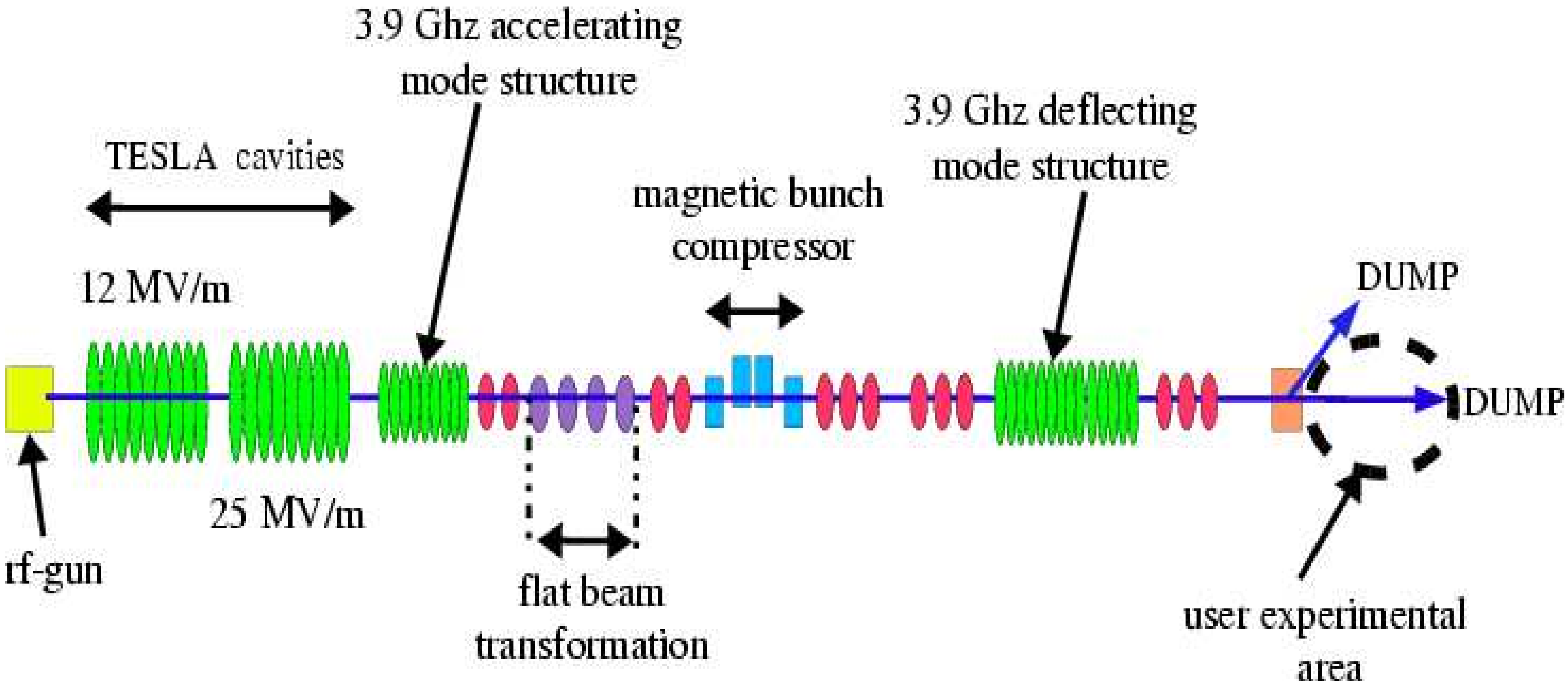
- Laser operates in the TEM_{01}* mode, since it provides the largest possible Ez-field.



- With 15 MeV beam, there is problem with phase slippage and large energy gain is not achievable at A0 **(experiment needs energy upgrade)**
- **Status**: laser ready, experiment in preparation (choice of structure,...)

FNPL upgrade

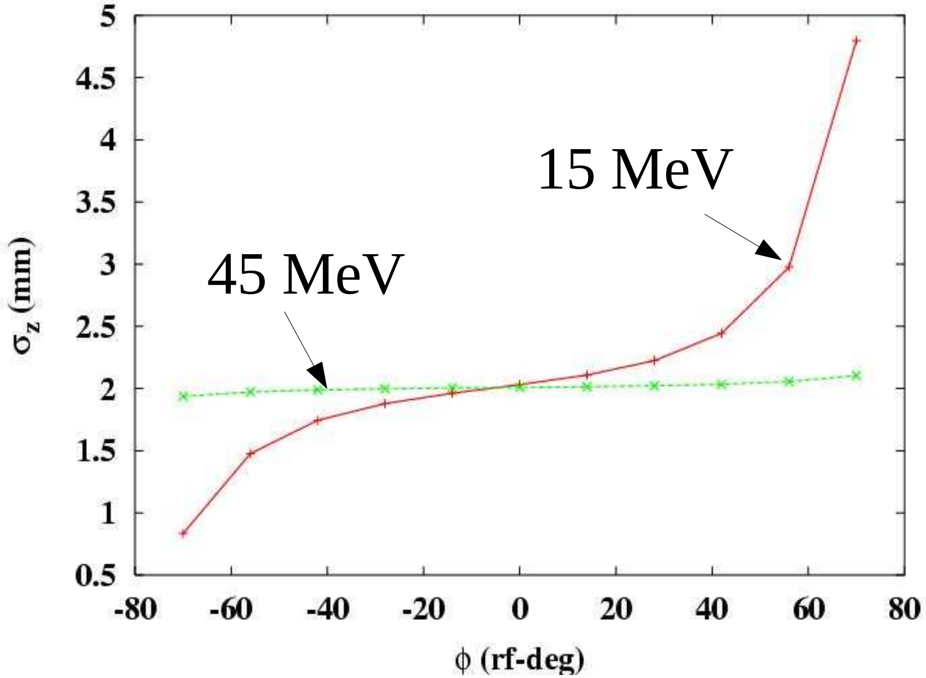
- DESY has offered to give a TESLA cavity (Grad.>25 MV/m)
- Proposed upgrade also incorporate the "CKM deflector" (3.9 GHz deflecting cavity) and a 3.9 Ghz accelerating mode cavity being developed at FNAL in the context of TTF-FEL 2 accelerator



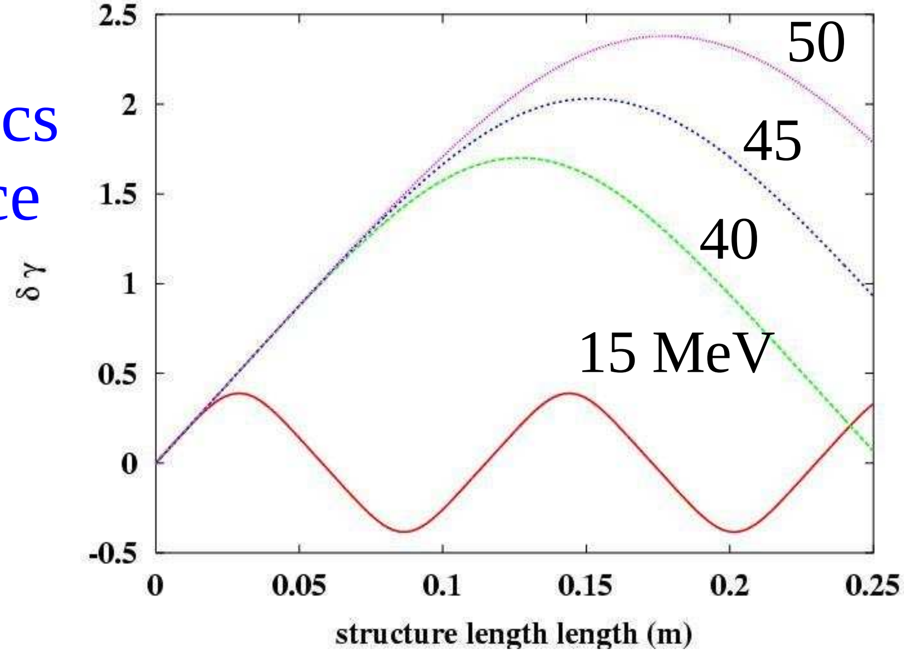
Benefits of FNPL operation at higher energy

- Beam less space-charge-dominated
  ↳ better control of beam envelope

- "Rigid" longitudinal beam dynamics
  ↳ rf-based longitudinal phase space measurements possible



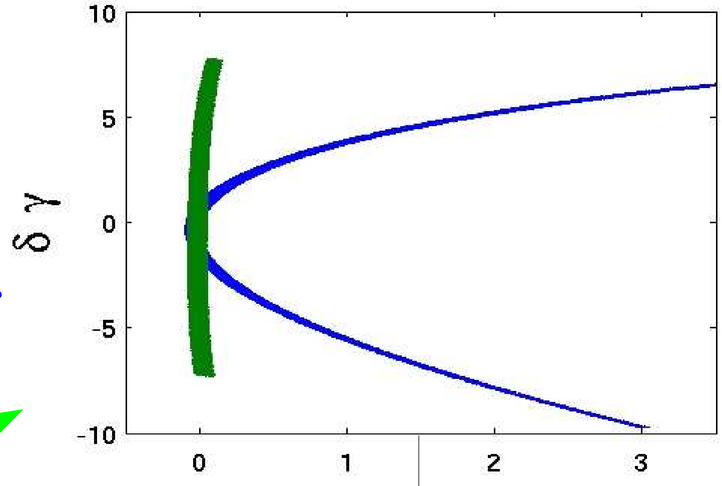
Laser acceleration: energy gain



- Laser acceleration experiment:
  ↳ phase slippage between e- and laser field less important

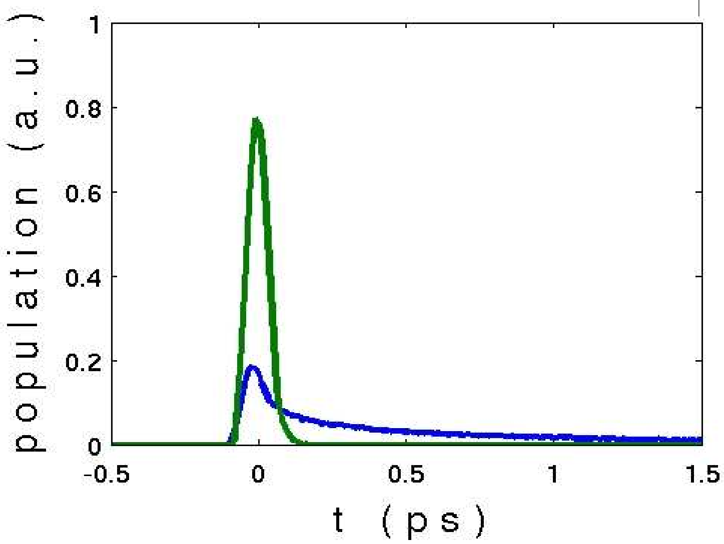
Motivation for the 3.9 Ghz cavities

- **Deflecting cavity** developed for CKM experiment (see L. Bellantoni's talk). Other possible applications include crab-crossing technique, rf-separator, and beam diagnostics.
- Installation at FNPL : characterization with beam, and beam diagnostics.



(z,δγ) after magnetic compression

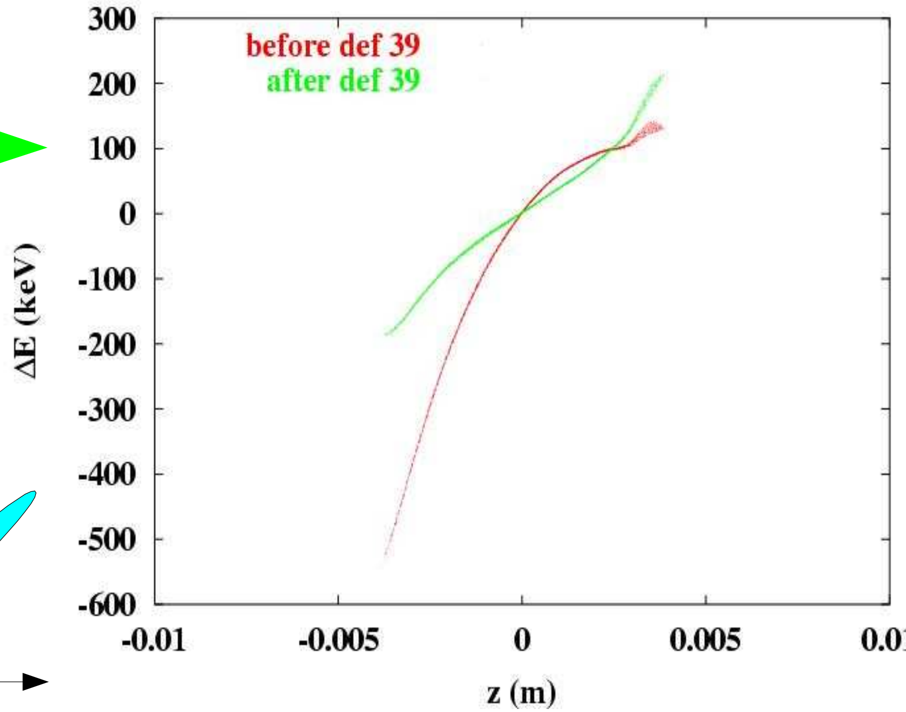
- **Accelerating cavity** used for linearization of the longitudinal phase space to achieve high peak current (application at TTF-FEL-2, X-Ray FEL, TESLA post-damping ring compressor, LUX proposal at LBNL, etc...).

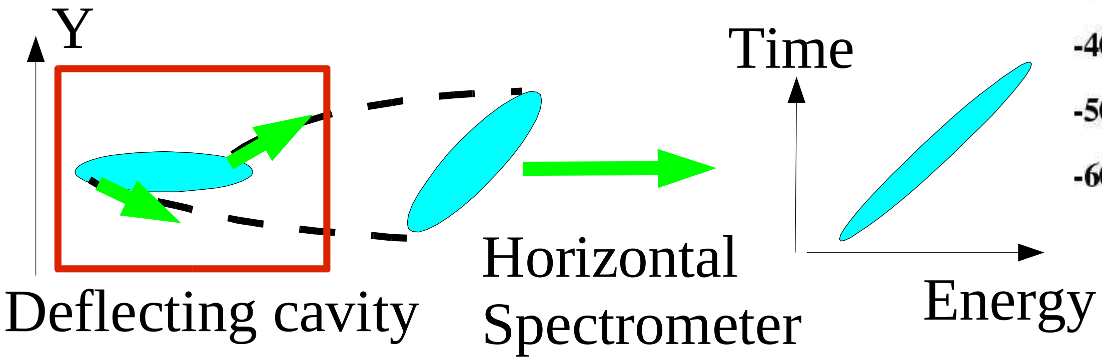


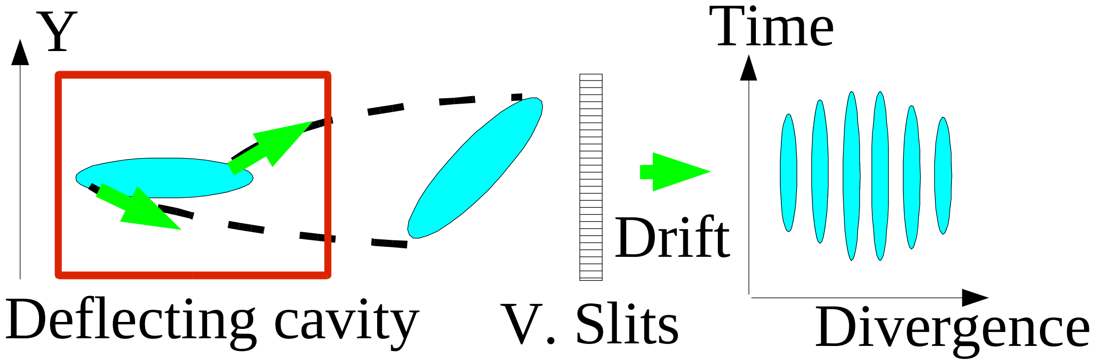
Charge density after compression

Longitudinal phase space manipulation and diagnostics

- Test and optimization of the longitudinal phase space linearization scheme to increase the peak current downstream of a bunch compressor

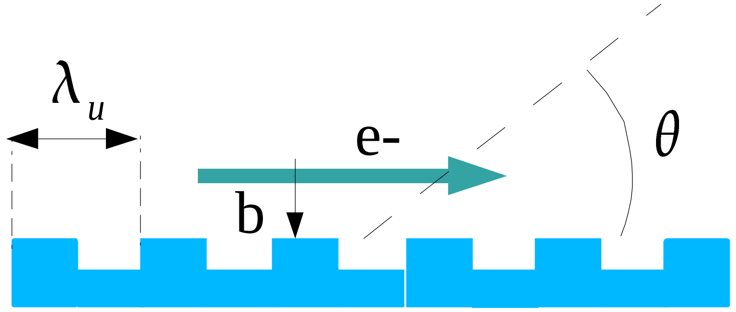






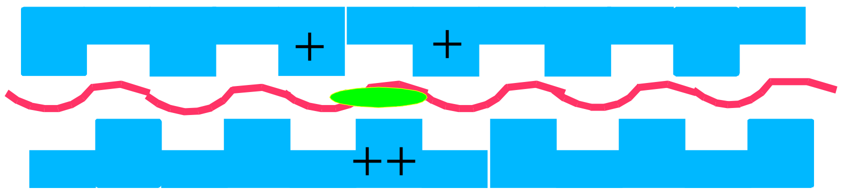
- Longitudinal and time-dependent transverse phase spaces measurements (using the CKM cavity)

Application of compressed flat beam: grating-based radiation sources



$$\lambda = \frac{\lambda_u}{n}\left(\beta^{-1} - \cos(\theta)\right)$$

- Flat beams may be used to generate Smith-Purcell (S-P) radiation in an efficient way $\dfrac{dW}{d\Omega\, d\omega} \propto e^{-b\,k(\varphi,\theta)}$
- SASE-like amplification of S-P radiation possible when high peak current bunches are used
- High peak current flat beams may also be used for a proof-of-principle of the image charge undulator principle (ICU)
- ICU configuration can yield self amplification in a single pass similarly to FEL based on undulators



- Such ICU-based radiation source open possibilities for more compact short wavelength FELs

Summary

- Despite its modest financial support, FNPL has made significant contributions to accelerator R&D (flat beam production, plasma-wakefield acceleration, progress on laser-based acceleration, on-going work on novel beam diagnostics)

- Foreseen short-term upgrade will enhance FNPL capabilities (energy, diagnostics) and is mandatory for the laser acceleration exp.

- FNPL and related R&D has been a key partner in the TESLA collaboration (e.g. rf-gun and 3.9 Ghz section design)

- **FNPL is associated with Universities: presently three graduate students are pursuing their Phd work:**
  Yin-e Sun (U. of Chicago), Rodion Tikhoplav (U. of Rochester), Matthiew Thompson (UCLA)

Contributors to the Physics program

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